BROOKHAVEN NATIONAL LABORATORY

DUNE/LBNF Beamline Designs and $\nu_\mu \rightarrow \nu_\tau$ Appearance BNL-SBU meeting Oct 4th, 2016

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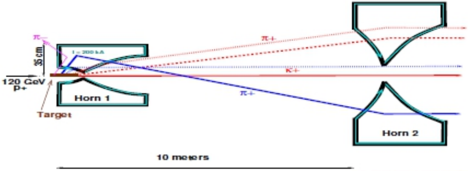
Outline

Example: NuMI Target and Horns

Target Region Components



NuMI Target

6.4 x 15 mm^2 graphite segments.

1m long = 1.9 interaction lengths.

$\mathcal{O}(10)$ KW beam power at 1 mm beam width.

Water cooled.

Horn 1

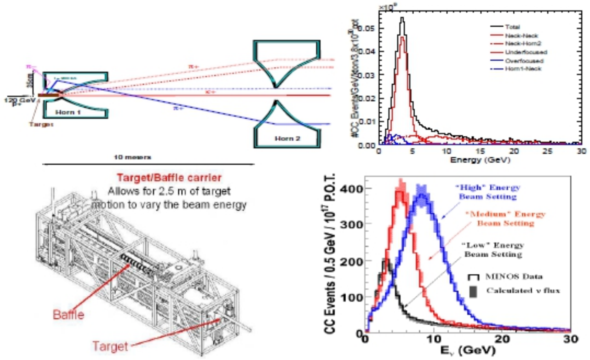
Horn 2

Parabolic magnetic lens.

3T at 200 kA

Example: NuMI Target and Horns

NuMI Beam Spectrum

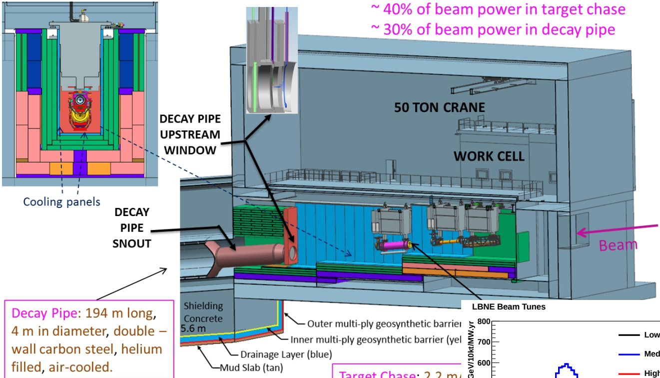


Move target w.r.t to Horn 1: -10cm (LE), -100cm (ME), -250cm (HE)

Beam is 92% ν_μ, 6.5% $\bar{\nu}_\mu$, 1.5% $\nu_e + \bar{\nu}_e$

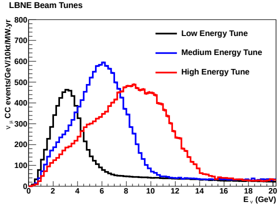
The LBNF Beamline CDR Design

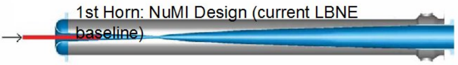
Advanced conceptual design with upgraded NuMI-style focusing. Horn location fixed but *tunable* by using movable target:



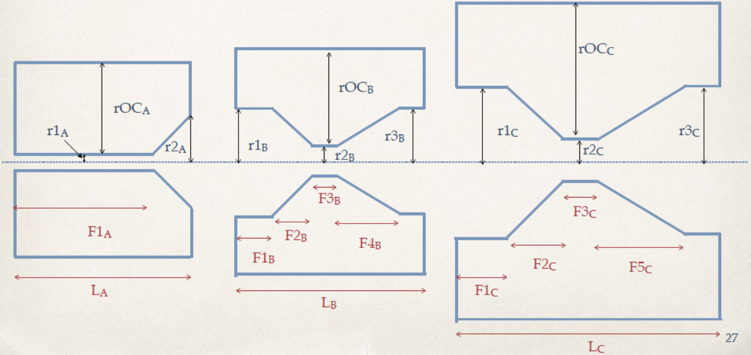
Decay Pipe: 194 m long, 4 m in diameter, double – wall carbon steel, helium filled, air-cooled.

Target Chase: 2.2 m/ air-filled and air & w





Horn Parameters



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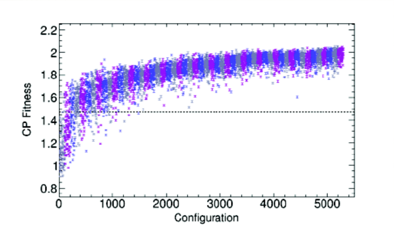
Optimization of Focusing System Geometry for CPV

Optimization result with a genetic algorithim

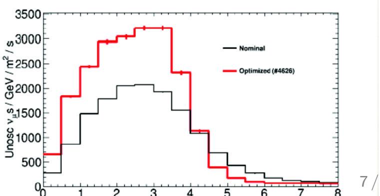
Optimization w/ Spherical Target

- Current status of optimization:



We wanted to include this optimization in the BOTF Interim Report (first draft finished and will be available soon), so I took a snapshot at a slightly earlier point in the optimization (seen here, and discussed more on following pages)

Best Fitness is 2.05
(Reference beam is 1.47)

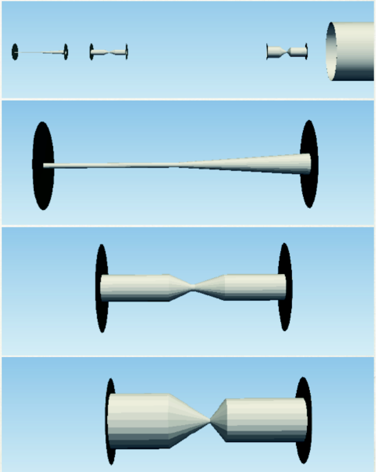


Optimization of Focusing System Geometry for CPV

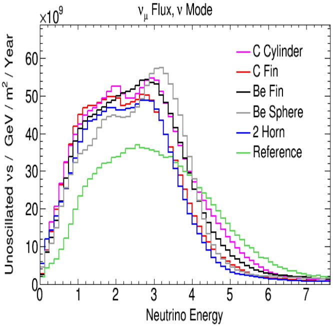
Laura Fields

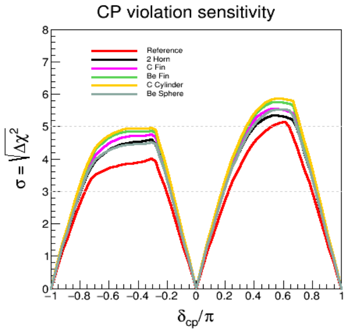
Cylindrical Target Optimization Results

Parameter	Lower Limit	Upper Limit	Unit	
Horn A: L_A	1000	4500	mm	3717
Horn A: $F1_A$	1	99	%	51
Horn A: $r1_A$	20	50	mm	33
Horn A: $r2_A$	20	200	mm	147
Horn A rOC_A	200	650	mm	630
Horn B: L_B	2000	4500	mm	2551
Horn B: $F1_B$	0	100	%	37
Horn B: $F2_B$	0	100	%	12
Horn B: $F3_B$	0	100	%	2
Horn B: $F4_B$	0	100	%	16
Horn B: $R1_B$	50	200	mm	186
Horn B: $R2_B$	20	50	mm	47
Horn B: $R3_B$	50	200	mm	179
Horn B: ROC_B	200	650	mm	633
HornB: Z position	2000	17000	mm	5453
Horn C: L_C	2000	4500	mm	2694
Horn C: $F1_C$	0	100	%	30
Horn C: $F2_C$	0	100	%	21
Horn C: $F3_C$	0	100	%	2
Horn C: $F4_C$	0	100	%	9
Horn C: $R1_C$	50	550	mm	388
Horn C: $R2_C$	20	50	mm	26
Horn C: $R3_C$	50	550	mm	306
Horn C: ROC_C	550	650	mm	620
Horn C: Z Position	4000	19000	mm	17836
Target Length	0.5	2.0	m	1.98
Beam spot size	1.6	2.5	mm	2.1
Target Radius	9	15	mm	7.8
Proton Energy	60	120	GeV	108
Horn Current	150	300	kA	270



Optimization of Focusing System Geometry for CPV

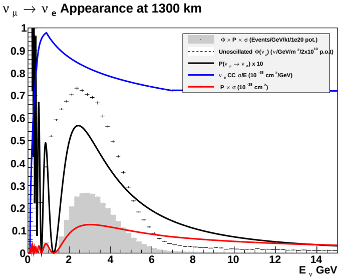


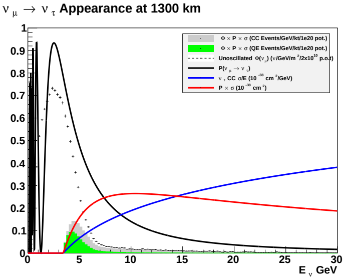


BOTF result: Significant gain in flux < 3 GeV = CPV gain

$\nu_\mu \to \nu_\tau$ Appearance Fundamentals

LBNF reference design (NuMI focusing) low energy tune

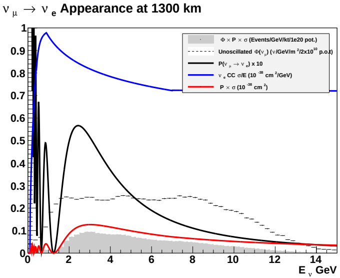


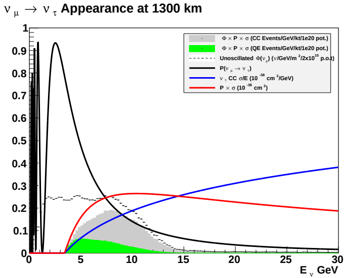


$\nu_\mu \to \nu_e$ 310 events **$\nu_\mu \to \nu_\tau$ 190 events**
in 40 ktons, 1 year at 1.2 MW

$\nu_\mu \rightarrow \nu_\tau$ Appearance Fundamentals

LBNF reference design (NuMI focusing) higher energy tune





$\nu_\mu \rightarrow \nu_e$ 230 events **$\nu_\mu \rightarrow \nu_\tau$ 530 events**
in 40 ktons, 1 year at 1.2 MW at 1300km

$\nu_\mu \to \nu_\tau$ Appearance Fundamentals

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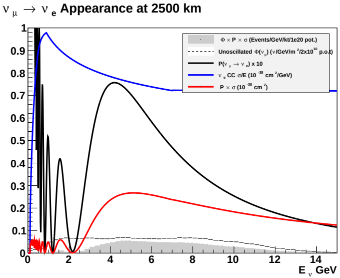
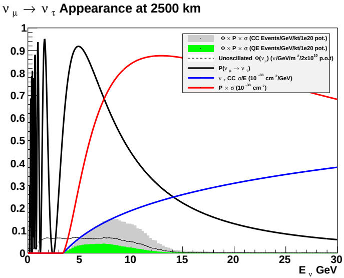
LBNF reference design (NuMI focusing) higher energy tune

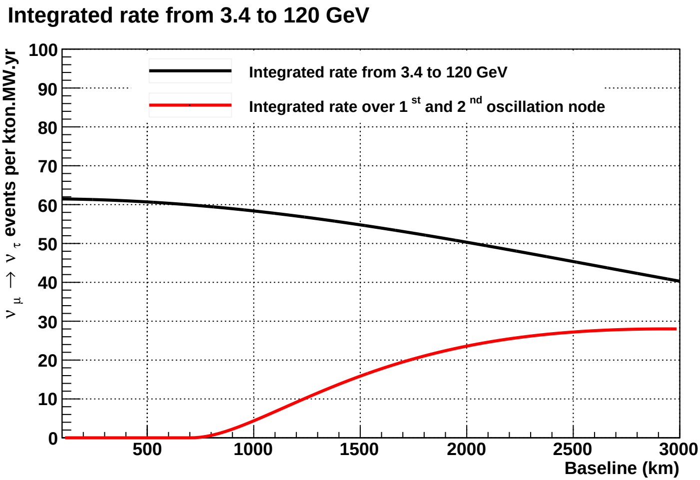




$\nu_\mu \to \nu_e$ 150 events **$\nu_\mu \to \nu_\tau$ 410 events**
in 40 ktons, 1 year at 1.2 MW at 2500km

Are we at the right baseline?

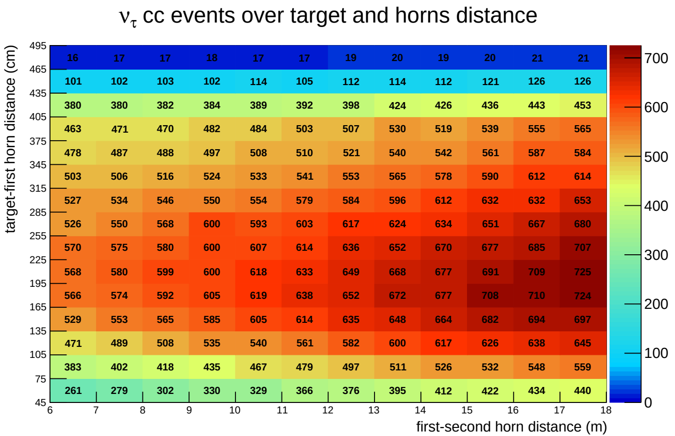
Rates with a 120 GeV perfect focused beam and a 400m decay channel:



Depends on how you focus !!. Baseline is not a fundamental limitation.

Optimize LBNF Reference Design for ν_τ

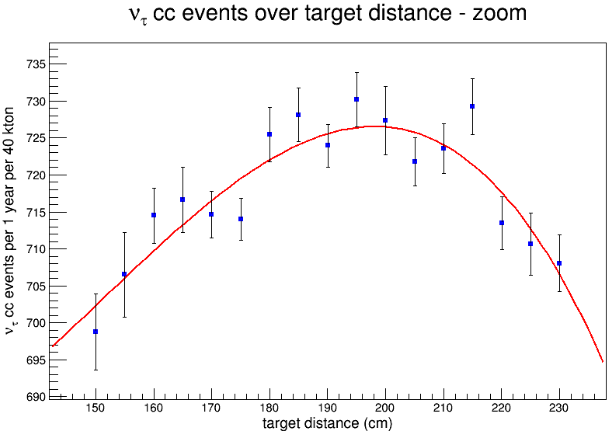
From Letizia Parato (G4LBNF, detailed geometry, GENIE cross-sections):



Need to push the horns as further away as possible

Optimize LBNF Reference Design for ν_τ

From Letizia Parato (G4LBNF, detailed geometry, GENIE cross-sections):



A target $\sim$ 2 m away from NuMI Horn 1 is optimal

Optimize LBNF Reference Design for ν_τ

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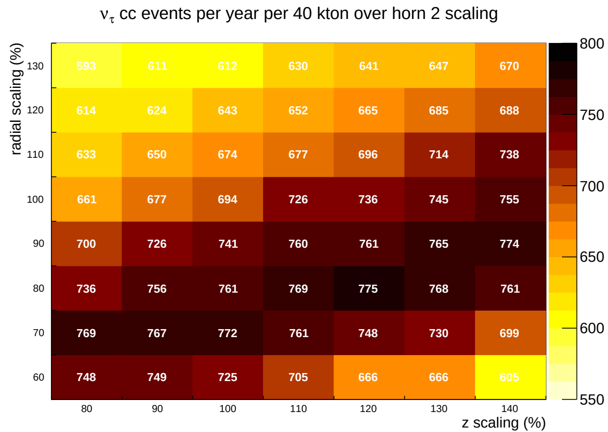
Neutrino Beamline Basics

Reference LBNF beam design

Optimization for ν_τ Appearance

Summary

From Letizia Parato (G4LBNF, detailed geometry, GENIE cross-sections):



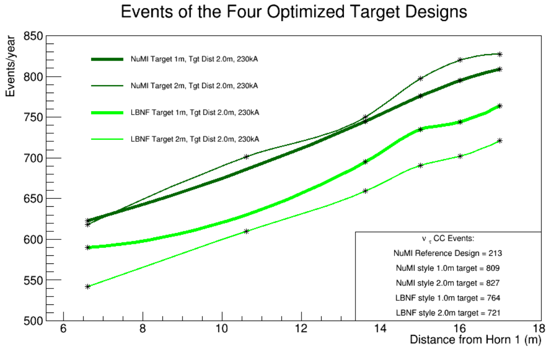
Further optimization of horns increases yield.

Optimize LBNF Reference Design for ν_τ

From Michael Dolce (G4LBNE v2, simplified geometry, GLoBeS cross-sections):

NuMI target: 120 GeV $\sigma_p = 1.5$mm; graphite box 1.754 g/cm^3; 6.4mm W x 20mm H x 0.9538m or 2.3719m L

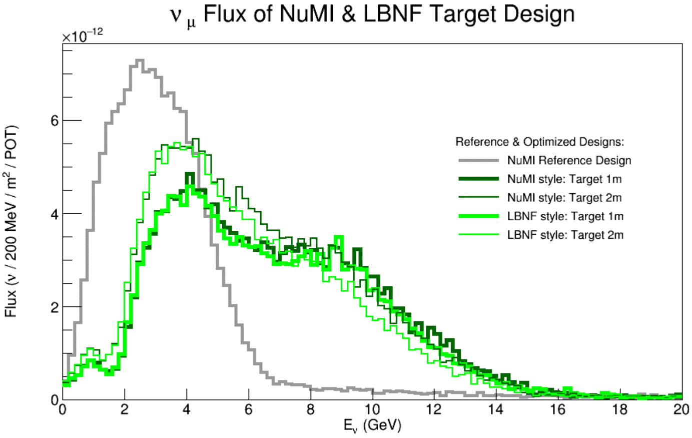
LBNF target: 120 GeV $\sigma_p = 1.7$mm; graphite box 1.754 g/cm^3; 10mm W x 20.73mm H x 0.9538m or 2.3719m L



Need a target that produces more pions from primary p^+ interactions.

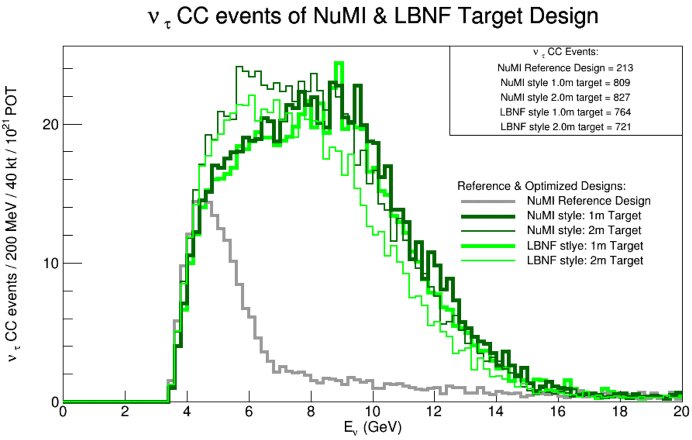
Optimize LBNF Reference Design for ν_τ

From Michael Dolce (G4LBNE v2, simplified geometry, GLobeS cross-sections):



Optimize LBNF Reference Design for ν_τ

From Michael Dolce (G4LBNE v2, simplified geometry, GLoBeS cross-sections):



Summary and Conclusions

- **By varying the tune of the reference LBNF 2-horn design (NuMI-like), we can increase the number of ν_τ appearance events from 130 CC events with the optimized 3-horn design ($\sim$ 200 with the reference LBNF design) to $\sim$ 720 CC events per 40 kton-year !**
- **2 completely independent studies by Letizia Parato and Michael Dolce indicate that for the reference LBNF NuMI-like focusing system, the optimal tune for ν_τ apperance is with the horns the maximum distance apart allowed by the expanded chase $\sim$ 17m, 230kA and a target 2m from Horn 1.**
- **Preliminary studies indicate target optimization is needed to increase the number of pions from primary proton interactions. Challenge at 1.2MW or higher.**

Further Studies - Opportunities for Collabortion

- **Using GLoBeS and DUNE FastMC (parameteric simulation) develop a full sensitivity analysis to ν_τ appearance in DUNE/LBNF taking into account smearing and backgrounds**
- **Apply machine learning techniques to the double parabolic horn designs to optimize for ν_τ appearance. This requires development of a metric based on sensitivity studies.**
- **ProtoDUNE data analysis to improve input to FastMC ν_τ selection based on fully reconstructed hadron and electron shower resolutions.**
- **Co-ordinate with the BSM and Long-Baseline PWG on the final design high energy focusing system that expands the physics reach beyond ν_τ appearance as well.**